



**US Army Corps
of Engineers**

**The Hydrologic
Engineering Center**

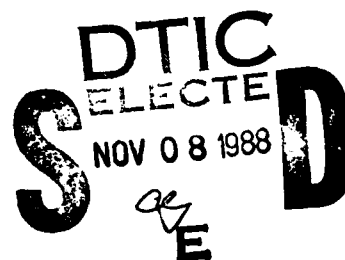
AD-A202 632

**DEVELOPMENT, CALIBRATION AND
APPLICATION OF RUNOFF FORECASTING
MODELS FOR THE ALLEGHENY RIVER BASIN**

By William J. Charley and John C. Peters

TECHNICAL PAPER NO 121

June 1988



88 11 08 048

DEVELOPMENT, CALIBRATION AND APPLICATION OF RUNOFF FORECASTING MODELS FOR THE ALLEGHENY RIVER BASIN²

William J. Charley and John C. Peters¹

Introduction

The U.S. Army Corps of Engineers is responsible for operating several hundred reservoirs throughout the United States. Many of the reservoirs are multiple purpose, with flood control as a primary purpose. Day-to-day operational decisions are generally made in water control centers located in the Corps' district offices. Some of these offices utilize a water-control software system developed by the Hydrologic Engineering Center (Pabst and Peters, 1983), which facilitates the decision-making process with capabilities for processing meteorologic and hydrologic data, forecasting runoff and simulating reservoir system performance. A component of the software system is computer program HEC1F (Peters and Ely, 1985), which performs runoff forecasting. The focus of this paper is on application of HEC1F in making short-term (3 to 5 day) forecasts for the 11,733 square mile (30,440 sq. km.) Allegheny River Basin, which contains nine flood control reservoirs operated by the Pittsburgh District, Corps of Engineers. Following a brief overview of the nature and scope of the water control software system, the intended application of HEC1F is provided. The characteristics of the Allegheny Basin, data collection networks, and forecast needs are described, as well as the approach used for model calibration and initial results. Finally, comments are made regarding the present status of model development and usage, and plans for the future. (FR)

Nature and Scope of the Software System

Figure 1 illustrates the major elements of the water control software system. A key component is the Hydrologic Engineering Center's Data Storage System (DSS), which is designed for efficient storage of time series data. Data stored in the DSS may consist of raw data, processed data (i.e., data that has been transformed, verified, filled-in, etc.), and data developed by various simulation programs (e.g., subbasin-average hyetographs, discharge hydrographs, reservoir elevation or reservoir storage versus time relationships, etc.). Rating curves and other similar data can also be stored in the DSS (HEC, 1987a).

¹Hydraulic Engineers, U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.

²Presented at the ASCE 3rd Water Resources Operations and Management Workshop, June 1988, Fort Collins, Colorado.

Sources of data encompassed by the Data Acquisition element of Figure 1 include data obtained

1. directly by satellite telemetry and other radio-based systems,
2. by computer-to-computer link with the National Weather Service's Automated Field Operations Service (AFOS),
3. from telemark and other sources (entered automatically or manually into DSS),
4. from dam-tenders and other field offices.

The "analysis" element of Figure 1 contains 3 primary programs: (1) PRECIP, which performs spatial averaging of gaged precipitation data to provide subbasin-average hyetographs, (2) HEC1F, which computes runoff from precipitation, and (3) HEC-5, which simulates and computes releases for a reservoir system. Another component, SNOSIM (Hoggan et al., 1987), is used to simulate snow accumulation and snowmelt for use in conjunction with HEC1F.

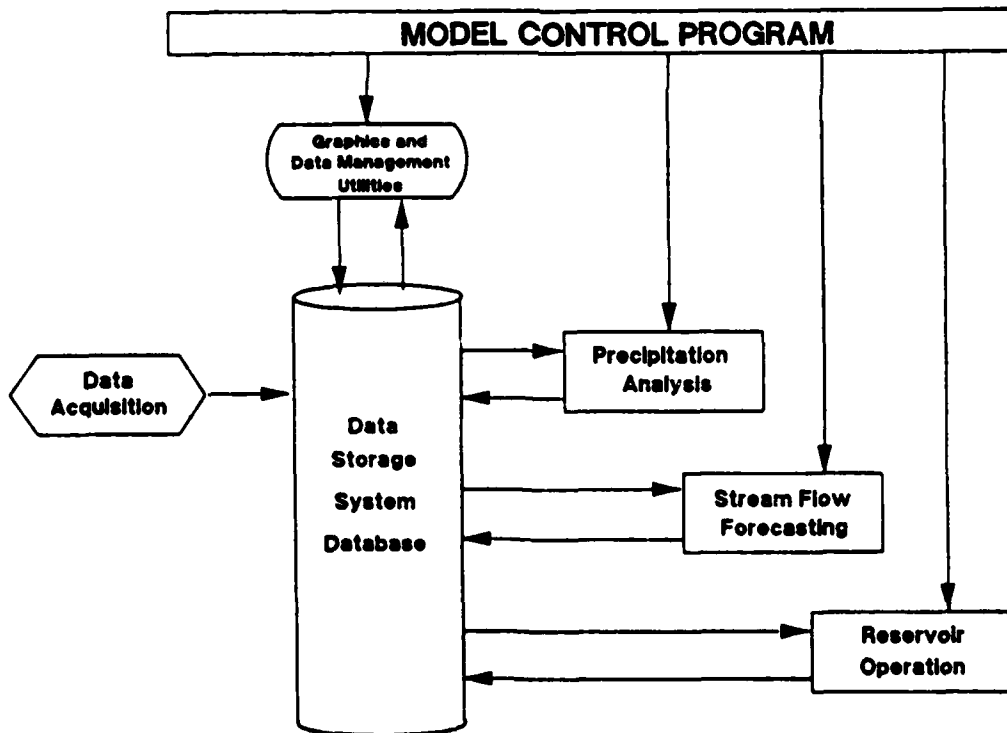
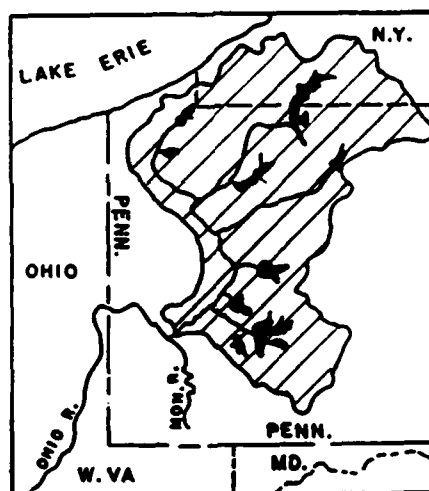


Figure 1. Water Control Software System Diagram

Associated with the DSS is a set of data management utility programs that enable plotting, tabulating, editing, etc., of stored data. To facilitate use of the software system, the interactive program MODCON (for Model Control) provides capabilities to review current data availability, set parameters for forecasts and operations simulations, execute forecasting models, review results, and set future precipitation and operations parameters.

Allegheny River Basin and Reservoir System

The Allegheny River Basin, with a drainage area of 11,733 square miles (30,390 sq. km.), is located in the northwest corner of Pennsylvania and extends into the southwest corner of New York as depicted in Figure 2. The basin is about 160 miles (257 km.) long and 73 miles (117 km.) wide, with topography that varies from narrow canyons to wide flood plains. Elevations range from 710 feet (216 meters) at Pittsburgh to almost 3000 feet (914 meters) in the Allegheny Mountains, which form the eastern border of the basin. The vegetation varies from grasslands to dense forest. The Allegheny River joins the Monongahela River at Pittsburgh to form the Ohio River.



Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input checked="" type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

Figure 2. Allegheny River Basin

The climate of the Allegheny Basin is temperate and humid with a substantial seasonal variation in temperature. Frequent and rapid changes in weather are due to frontal air mass activity. Precipitation is distributed throughout the seasons with a normal annual total of about 40 inches (100 cm.). The normal monthly precipitation is highest in July with 4.3 inches (11 cm.) and lowest in February with 2.6 inches (6.6 cm.). Average seasonal snowfall ranges from 40 inches (100 cm.) near Pittsburgh to 170 inches (430 cm.) in New York. Snow cover is generally subject to melting throughout the winter season and is frequently a contributing factor to winter and early spring flood runoff. Winter ice jams on the upper Allegheny have caused significant flooding.

A key element of the flood control reservoir system is Allegheny Reservoir, which controls runoff from 2180 square miles (5650 sq. km.), representing 19 percent of the basin. (A Basin Schematic is provided in Figure 3.) Flood control storage in the reservoir provides an equivalent depth of 5.22 inches (13.3 cm.) of water over the

upstream area. The reservoir is located 135 miles from the confluence with the Monongahela River at Pittsburgh. Eight additional Corps reservoirs within the basin also provide flood control. The area upstream of all nine reservoirs is 45 percent of the total basin area. Four of the nine reservoirs are multi-purpose; five are essentially dedicated to flood control. Two reservoirs are operated for water quality purposes. Conemaugh, the second largest reservoir, limits releases to minimize effects of acid mine drainage, and East Branch Reservoir maintains releases to insure adequate dissolved oxygen downstream.

The Corps maintains 57 data collection platforms (DCPs) in the basin. Solar panels provide power to DCPs which enables them to operate in remote areas without access to commercial power or telephone service. Typically, the DCPs record stage, precipitation and air temperature data every hour, then transmit that data to the Corps' Ohio River Division office in Cincinnati once every four hours, via the GOES (Geostationary Operational Environmental Satellite) system. The Cincinnati office decodes the data, then transmits it to the District office where it is stored in a data base until a forecast is made. The District also receives precipitation data from the National Weather Service AFOS, and reservoir storage and related data from the field offices at the reservoirs.

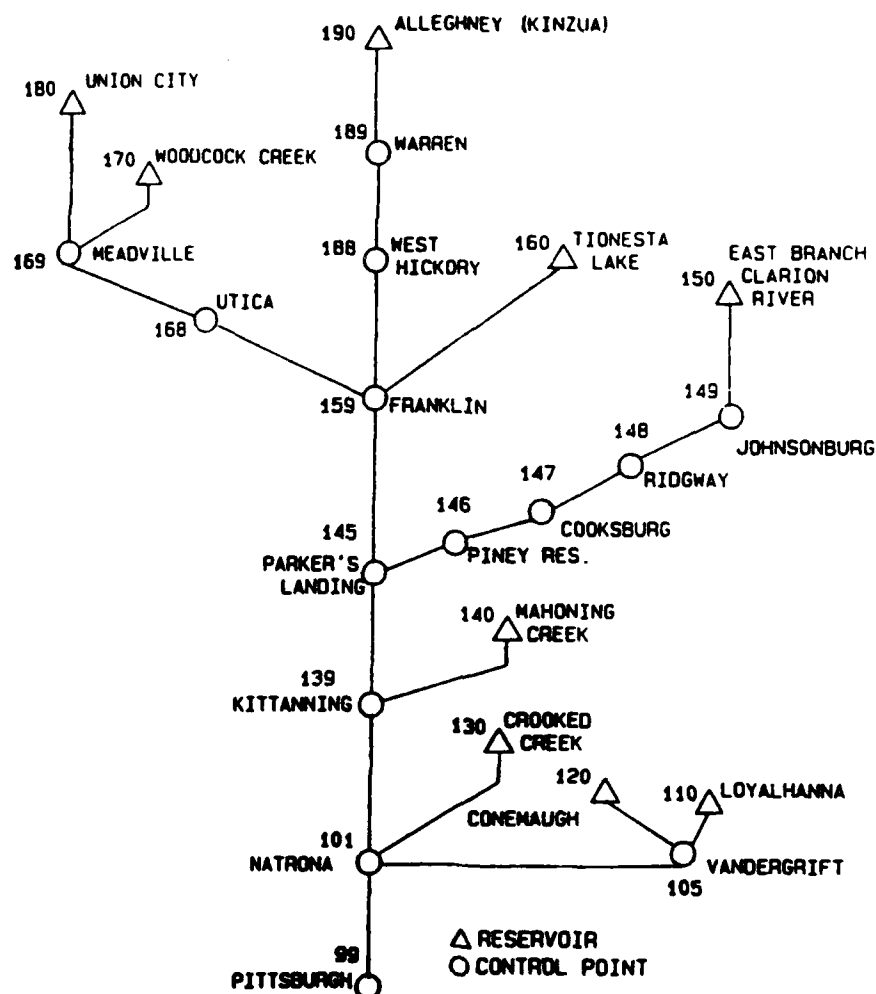


Figure 3. Allegheny Basin Reservoir System

Capabilities and Intended Application of HEC1F

Computer program HEC1F is an adaptation of computer program HEC-1 (HEC, 1985), which is widely-used in flood-runoff analysis for purposes such as project planning, flood-plain delineation and hydraulic-structure design. The basic HEC-1 capabilities for calculating runoff with a unit hydrograph approach from a multi-subbasin watershed, and for parameter optimization, are retained in HEC1F. However, HEC1F contains additional capabilities that facilitate the task of runoff forecasting. Aspects of application of HEC1F for forecasting are as follows:

1. Forecasting with HEC1F is intended to involve a "hands-on" process by which the analyst can readily compare simulated hydrographs with observed hydrographs (up to the time-of-forecast) and adjust loss rates, or perhaps other parameters, to improve results. Subbasins are aggregated into groups (called zones) for purposes of specifying values for loss rate and base flow parameters. For example, a watershed with 30 subbasins might be subdivided into 4 or 5 zones. Loss rate and base flow parameters may then be specified on a zonal basis, rather than a subbasin basis.
2. Forecasting is performed in two separate executions of HEC1F. In the first, unit hydrograph, loss rate and base flow parameters are optimized for gaged headwater subbasins. The time window "T" in Figure 4 is the period over which an objective function to optimize the above parameters is evaluated. The window is approximately equal to the time base of the unit hydrograph for the subbasin. The objective function that is minimized by a univariate gradient technique (Ford et al., 1980) is as follows:

$$\text{STDER} = \sqrt{\frac{\sum_{i=1}^N (QOBS_i - QCOMP_i)^2 * WT_i}{N}} \quad (1)$$

where

STDER = objective function

QOBS_i = ordinate i of the observed hydrograph

QCOMP_i = ordinate i of the computed hydrograph

WT_i = weighting factor applied at ordinate i

N = total number of hydrograph ordinates encompassed by the objective function

The equation defining the weighting factor is as follows:

$$WT_i = \left(\frac{J}{N - 1} \right)^2 \quad (2)$$

where J = number of Δt intervals from the beginning of the time period for parameter estimation (T) to the time of ordinate i

The objective function given in equation (1) is a quantitative measure of the goodness of fit of the calculated hydrograph to the observed hydrograph. The weighting factor defined by equation 2 has a value of 1 at the time-of-forecast, and diminishes to a value of 0 at the beginning of the time window " T ". The purpose of the weighting is to insure a relatively close fit of the calculated to the observed hydrograph in the vicinity of the time-of-forecast.

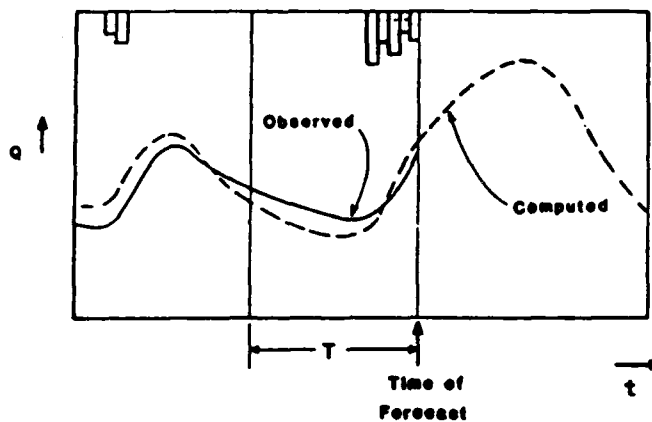


Figure 4. Parameter Estimation of Gaged Headwater Subbasins

The optimization process has built-in constraints that prevent physically unreasonable values for the parameters to be optimized (HEC, 1987b). For example if the rainfall is concentrated very near the time-of-forecast, there will be little hydrograph "rise" with which to optimize parameters, so that optimization is permitted only for base flow parameters.

3. Following the parameter optimization application of HEC1F, the analyst reviews optimization results and parameter estimates as an aid to setting zonal values of loss rate and base flow parameters for the remainder of the basin.
4. The second application of HEC1F performs runoff computations, and routing and combining operations throughout the basin. At each location for which an observed hydrograph is available, "blending" can be performed. A blended hydrograph consists of the observed hydrograph up to the time-of-forecast, a transition from the observed to the computed hydrograph for six time

intervals following the time-of-forecast, and the computed hydrograph from the end of the transition through the remainder of the forecast period. The transition is computed by linearly diminishing the "error" (difference between the observed and computed discharge) at the time-of-forecast to zero over the six time intervals. The blended hydrograph is used in subsequent routing computations.

5. Forecasts may be evaluated by reviewing several summary tables (examples of which are provided in Figure 5) and by viewing plots of computed and observed hydrographs for locations of interest. If necessary, zonal values for parameters can be adjusted and an additional HECIF "run" executed to improve results.

Forecasts developed with HECIF take into account precipitation and reservoir releases up to the time-of-forecast. The software system provides the capacity to specify future precipitation and future reservoir releases so that "what if" conditions can be readily evaluated. In order for future reservoir releases to be included in the forecasts, such releases can be manually entered with the MODCON program for use by HECIF. Alternatively, future releases can be determined with the reservoir system simulation program, HEC-5.

PARAMETER ESTIMATION ERROR SUMMARY										
RUN DATE: 10MAY88 TIME: 12:52										
TIME OF FORECAST --- 0600 4 APR (PRECIPITATION ALT A)										
LOCATION	AREA SQ MI	--- FORECAST TIME ---			TIME FRAME HRS	----- FOR TIME FRAME -----				PPT EXCESS INCHES
		OBS FLOW CFS	CALC FLOW CFS	ERROR PCT		AVERAGE OBS CFS	FLOW CALC CFS	AVG ERROR PCT	ABS	
PALP	263	1440	882	-39	105	759	728	17		.20
BRFP	100	---	1120	---	33	---	411	---		.24
GUFF	46	570	544	-5	33	199	210	14		.27

PARAMETER ESTIMATES								
RUN DATE: 10MAY88 TIME: 12:52								
TIME OF FORECAST --- 0600 4 APR PPT ALT A INITIAL ESTIMATES								
LOCATION	BFFCST CFS/SQ MI	RTIOR	B.F. ZONE	STRTL INCHES	CNSTL IN/HR	L.R. ZONE	TP HOURS	CP
PALP	2.58	1.0011	1	0.000	0.110	1	20.00	0.30
	1.65	1.0083		0.000	0.110		20.00	0.30
BRFP	1.65	1.0083	1	0.000	0.110	1	5.00	0.40
	1.65	1.0083		0.000	0.110		5.00	0.40
GUFF	2.04	1.0016	1	0.000	0.111	1	5.01	0.38
	1.65	1.0083		0.000	0.110		5.00	0.40

Figure 5. Parameter Estimation Summary Table

Development and Calibration of HEC1F Models

Models for HEC1F are developed to provide information at key locations such as reservoirs and downstream control points, and must accommodate essential watershed and data network features. Development tasks include delineation of subbasins, and initial estimation of parameters for each subbasin and routing reach. These parameters are then calibrated with data from historic events. The models are subsequently "fine-tuned" with data from the current data collection network.

The delineation of subbasins involves consideration of the locations of current and anticipated DCPs which transmit stage, and hydrologic and meteorologic variability in the basin. Based on these considerations, the basin was divided into 53 subbasins, as depicted in Figure 6, of which 49 subbasins have stage gages at the outlet. Twenty of these are headwater subbasins (shaded in Figure 6) for which it is possible to optimize runoff parameters.

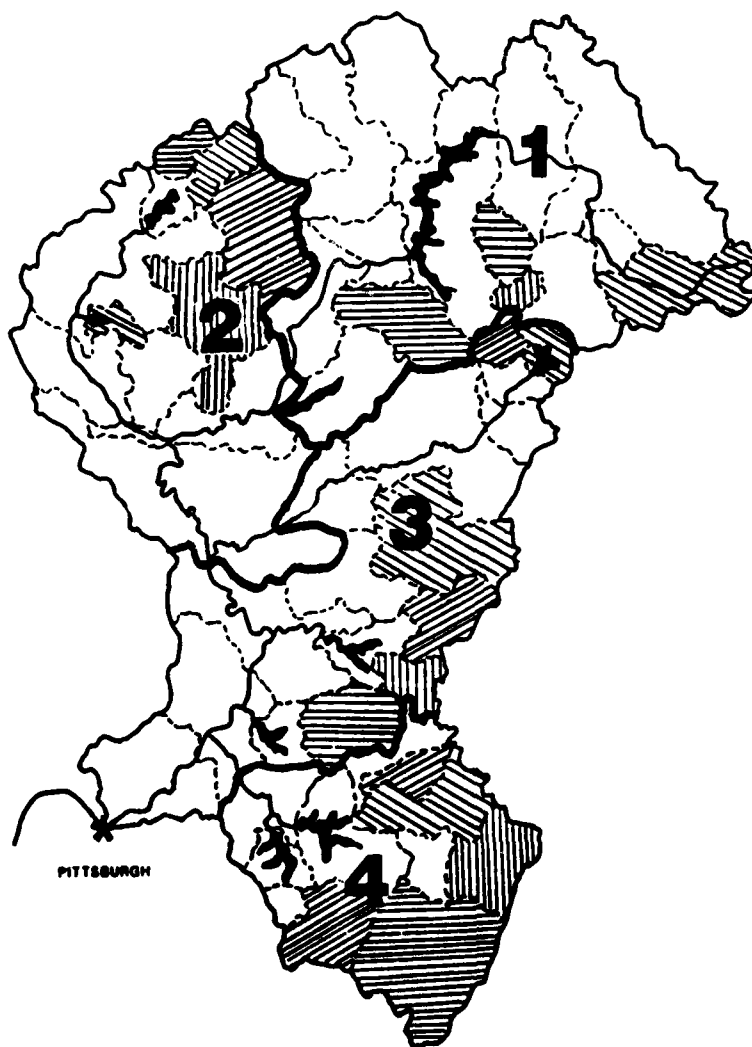


Figure 6. Allegheny Basin Subbasins and Zones

Values for unit hydrograph, loss rate and base flow parameters are required for each subbasin for which runoff is to be calculated. Values chosen are ultimately based on calibration. However, the adoption of reasonable initial values greatly facilitates the calibration process. Generally extensive hydrologic investigations are involved in planning and designing reservoirs, and results of these past studies can be very useful as an aid for developing initial parameter estimates. Such is the case for this study; substantial data, including unit hydrographs, were available.

The Pittsburgh District provided six-hour unit hydrographs for 36 of the subbasins. Although it is possible to use unit hydrographs expressed in coordinate form in HEC1F, a unit hydrograph must be defined in terms of the two Snyder parameters, TP and CP, if the optimization capabilities of the program are to be used. Unit hydrographs for all gaged headwater subbasins must therefore be represented by Snyder parameters for HEC1F. Snyder parameters are used for other subbasins to facilitate the making of adjustments during the calibration process, and to enable development of regional relations by regression analysis. The parameters are derived for a given unit hydrograph by using the optimization option of HEC1F to develop values for TP and CP to best fit the unit hydrograph. This procedure involves specifying one inch of rain with a duration equal to the duration of the unit hydrograph, and setting losses and base flow equal to zero.

Unit hydrograph parameters for remaining subbasins were derived with a variety of methods. In some cases, simple routing and combining or subtracting operations with available unit hydrographs was all that was required. In other cases, regional correlation relationships were used. For a number of the subbasins, parameters were estimated based on parameters for nearby subbasins and modified during the calibration process.

Muskingum routing criteria were available for most of the routing reaches from previous studies. Where criteria were not available, initial values were estimated by adjusting values for nearby reaches for travel-time differences as reflected in the length and slope of the reach. Calibration confirmed most of the routing coefficients provided, but changes were required for a few reaches to improve the fit of observed and calculated hydrographs at some downstream locations. It should be noted that the coefficients have been developed for periods of significant runoff. Experience with similar watersheds has indicated that different routing coefficients may be required for low flow conditions.

Three historical events (occurring in the years 1972, 1977 and 1983) were selected by the District office for purposes of calibration. Hourly flow data was supplied for those events for about one-half of the locations of the current DCPs. Hourly and daily precipitation records were obtained for a number of additional locations from the National Weather Service. The latter data was transferred from magnetic tape to a DSS file by use of the utility program NWSOSS (HEC, 1987a).

Two input files for HEC1F were developed. The first enables parameter optimization for gaged headwater subbasins, and the second enables calculation of runoff at all reservoirs, stream gages and other locations of interest. The first file was used to optimize parameters directly with data for the historical events. Figure 7 shows values for Snyder unit hydrograph parameters for the McCormick subbasin (labeled MCRP), a typical gaged headwater subbasin. A single set of values was adopted for the subbasin based on factors such as the quality of the historical data, and the goodness of fit of the computed to the observed hydrographs. This task was performed for each

gaged headwater subbasin for which historical data exists. The adopted values are used as initial estimates when observed flow data is available for real-time optimization. If observed flow data is not available, the values are used without adjustment.

PARAMETER	INITIAL ESTIMATE	1972 EVENT	1977 EVENT	1983 EVENT	ADOPTED
TP (HOURS)	15.0	14.7	11.7	11.9	13.7
CP	0.50	0.51	0.41	0.73	0.45

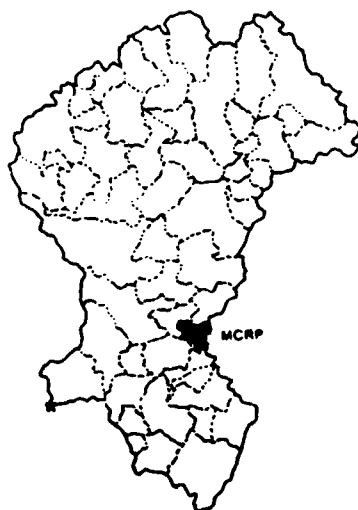


Figure 7. Optimized and Adopted Values for Synder Parameters at a Typical Headwater Subbasin

The second input file was used to calibrate parameters for the remaining (non-headwater) subbasins. The problem here is that there can be a large number of parameters that influence the simulated runoff at a given location, and calibration requires substantial judgment and trial and error adjustment. In general, the approach is to look for consistent bias in the comparison of calculated and observed hydrographs at a given location, and then adjust routing and/or unit hydrograph parameters in an attempt to obtain more consistent results.

During a real-time event, the forecaster needs to be able to quickly assign a reasonable estimate of loss rates and base flow parameters to each subbasin. To facilitate specification of parameters, the basin is divided into zones of similar hydrologic characteristics. During a forecast, HEC1F produces optimized loss rate and base flow parameters for each gaged headwater subbasin. The forecaster reviews these parameters and the associated forecasts, then selects the "best" estimate for each zone. These estimates are then used with the second input file to make basin-wide runoff forecasts. Although some flexibility is sacrificed by lumping subbasins into zones, it is necessary from the point of view of efficiency in making forecasts for a large basin with numerous subbasins.

The next step in the calibration process is to evaluate performance of the models by stepping through historical events as if they were occurring in real time. This involves optimizing parameters up to the time-of-forecast, assigning best fit parameters to each zone, then executing the forecast model and examining the results. Generally only minor adjustments to parameters are made at this stage.

As indicated previously, historical data are available for only about one half of the locations in the DCP network. It is therefore necessary to test the models and zonal subdivisions using the current data network. To accomplish this task, data is automatically retrieved every morning from the Pittsburgh District using a high speed modem. Forecasts made with this data provide information to enable additional model adjustments. An example of a forecast with data from the present network is shown in Figure 8 for April 3, 1988 at Natrona, a key downstream control point. Rain fell over the entire basin on the evening of the third. A plot of the forecasted hydrograph for the first forecast, made at 9 p.m., is depicted in Figure 8a. The dashed vertical line indicates the time-of-forecast; no data was known past the forecast time. The observed flows were added in later for comparison purposes, and reflect rain that occurred after the time-of-forecast as well as reservoir releases that had not been anticipated at the time-of-forecast. For this forecast, the peak was predicted to occur about 24 hours in the future, and was about 25% low. Another forecast, made three hours later at 12 midnight, as shown in Figure 8b, shows a substantial increase in the peak as compared to the earlier forecast. With the additional precipitation information over the three hours between forecasts, it was possible to forecast the peak more accurately. The forecasted peak is slightly early because routing coefficients are based on calibration with higher flows.

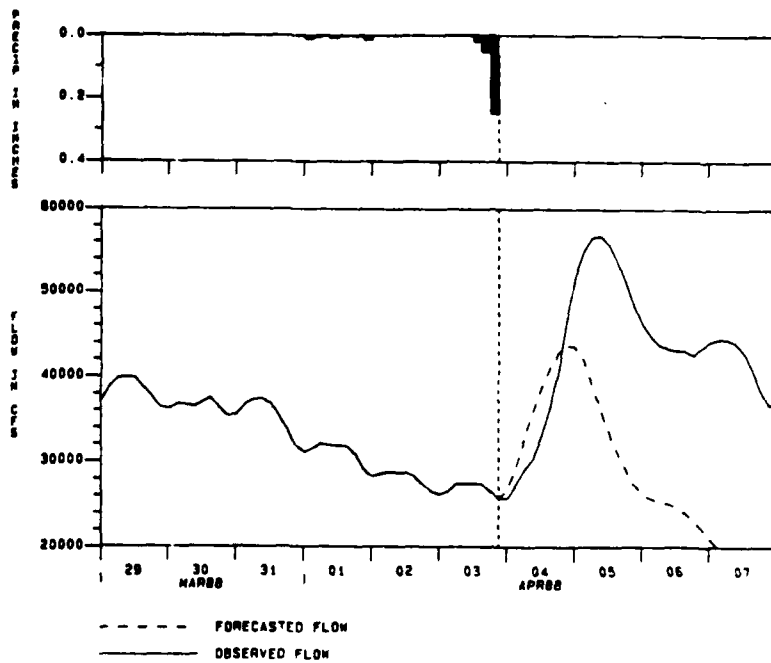
The calibrated HEC1F models are now in day-to-day use in the Pittsburgh District. As experience is gained in applying the models, and as further knowledge of the hydrologic response of the basin is acquired, additional adjustments to the models will be made.

Summary and Plans for the Future

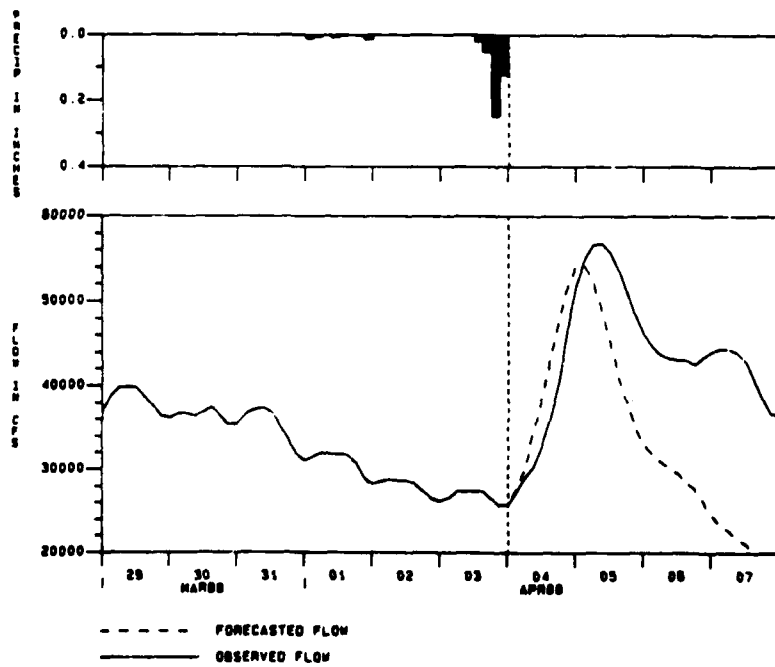
The development and calibration of HEC1F models for the Allegheny River Basin, and their use in conjunction with a water control software system, have been described. Similar models are in day-to-day use for several other basins tributary to the Ohio River, including the Scioto, Kanawaha, Muskingum and Monongahela. As experience is gained in using the capabilities described, the need for software enhancements and new tools becomes apparent.

The models seem to perform reasonably well for significant rainfall events, but simulation of minor rises is subject to substantial error because of uncertainty in estimating effective rainfall and limited capability for representing base flow. A new version of HEC1F that employs continuous soil moisture accounting is presently being tested. It is expected that with such a model the accuracy of forecasts for small events will improve, as will the accuracy of early forecasts in large events.

Components of the software system are being adapted for use on microcomputers. It is anticipated that a substantial portion of forecasts for operational purposes will be made on microcomputer using a local area network in the not-to-distant future.



(a) 9 p.m. Time-of-Forecast



(b) 12 Midnight Time-of-Forecast

Figure 8. Forecasted versus Observed Hydrographs at Natrona on April 3, 1988

Acknowledgements

The authors would like to thank Bruce Raabe for his work on this project. Appreciation is also expressed to Werner Loehlein and the Pittsburgh District Corps of Engineers for financing this project.

References

- Ford, D., E. Morris, and A. Feldman: Experience with Automated Calibration of a Precipitation-Runoff Model. Water and Related Land Resource Systems, Pergamon Press, New York, 1980.
- Hoggan, D., J. Peters, and W. Loehlein: Real-Time Snow Simulation Model for the Monongahela River Basin. Water Resources Bulletin, 23(6), 1987, 1141-1147.
- Pabst, A., and J. Peters: A Software System to Aid in Making Real-Time Water Control Decisions. Paper presented at the Technical Conference on Mitigation of Natural Hazards Through Real-Time Data Collection and Hydrological Forecasting. Technical Paper No. 89, Hydrologic Engineering Center, Davis, California, 1983.
- Peters, J., and P. Ely: Flood-Runoff Forecasting With HEC1F. Water Resources Bulletin, 21(1), 1985, 7-13.
- U.S. Army Corps of Engineers: HEC-1 Flood Hydrograph Package Users Manual. Hydrologic Engineering Center, Davis, California, 1985.
- U.S. Army Corps of Engineers: HECDSS Users Guide and Utility Program Manuals. Hydrologic Engineering Center, Davis, California, 1987a.
- U.S. Army Corps of Engineers: Water Control Software, Forecast and Operations. Hydrologic Engineering Center, Davis, California, 1987b.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE			UNLIMITED		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Paper No. 121			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Hydrologic Engineering Center U.S. Army Corps of Engineers		6b. OFFICE SYMBOL (If applicable) CEWRC-HEC	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State, and ZIP Code) 609 Second Street Davis, CA 95616			7b. ADDRESS (City, State, and ZIP Code)		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Water Resources Support Center		8b. OFFICE SYMBOL (If applicable) CEWRC	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code) Casey Building #2594 Ft. Belvoir, VA 22060-5586			10. SOURCE OF FUNDING NUMBERS		
PROGRAM ELEMENT NO.		PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.	
11. TITLE (Include Security Classification) Development, Calibration and Application of Runoff Forecasting Models for the Allegheny River Basin (Unclassified)					
12. PERSONAL AUTHOR(S) William J. Charley and John C. Peters					
13a. TYPE OF REPORT Technical Paper		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day) 1988 JUNE	
				15. PAGE COUNT 13	
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Rainfall-Runoff Simulation, Real-Time Water Control, Stream Flow Forecasting, Allegheny River Basin, HEC1F, HEC2SS		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) The U.S. Army Corps of Engineers is responsible for operating several hundred reservoirs throughout the United States. Many of the reservoirs are multiple purpose, with flood control as a primary purpose. Day-to-day operational decisions are generally made in water control centers located in the Corps' district offices. Some of these offices utilize a water-control software system developed by the Hydrologic Engineering Center, which facilitates the decision-making process with capabilities for processing meteorologic and hydrologic data, forecasting runoff and simulating reservoir system performance. A component of the software system is computer program HEC1F, which performs runoff forecasting. The focus of this paper is on application of HEC1F in making short-term (3 to 5 day) forecasts for the 11,733 square mile (30,440 sq. km.) Allegheny River Basin, which contains nine flood control reservoirs operated by the Pittsburgh District, Corps of Engineers. Following a brief overview of the nature and scope of the water control software system, the intended application of HEC1F is provided. The characteristics of the Allegheny Basin, data collection networks, and forecast needs are described, as well as the approach used for					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED		
22a. NAME OF RESPONSIBLE INDIVIDUAL William Charley, John Peters, Bill S. Eichert			22b. TELEPHONE (Include Area Code) (916) 551-1748		22c. OFFICE SYMBOL CEWRC-HEC

UNCLASSIFIED

Item 19 cont.

model calibration and initial results. Finally, comments are made regarding the present status of model development and usage, and plans for the future.

UNCLASSIFIED

TECHNICAL PAPER SERIES **(\$2.00 per paper)**

- | | | | |
|-------|---|-------|---|
| TP-1 | Use of Interrelated Records to Simulate Streamflow | TP-28 | Digital Simulation of an Existing Water Resources System |
| TP-2 | Optimization Techniques for Hydrologic Engineering | TP-29 | Computer Applications in Continuing Education |
| TP-3 | Methods of Determination of Safe Yield and Compensation Water from Storage Reservoirs | TP-30 | Drought Severity and Water Supply Dependability. |
| TP-4 | Functional Evaluation of a Water Resources System | TP-31 | Development of System Operation Rules for an Existing System by Simulation |
| TP-5 | Streamflow Synthesis for Ungaged Rivers | TP-32 | Alternative Approaches to Water Resource System Simulation |
| TP-6 | Simulation of Daily Streamflow | TP-33 | System Simulation for Integrated Use of Hydroelectric and Thermal Power Generation |
| TP-7 | Pilot Study for Storage Requirements for Low Flow Augmentation | TP-34 | Optimizing Flood Control Allocation for a Multipurpose Reservoir |
| TP-8 | Worth of Streamflow Data for Project Design - A Pilot Study | TP-35 | Computer Models for Rainfall-Runoff and River Hydraulic Analysis |
| TP-9 | Economic Evaluation of Reservoir System Accomplishments | TP-36 | Evaluation of Drought Effects at Lake Atitlan |
| TP-10 | Hydrologic Simulation in Water-Yield Analysis | TP-37 | Downstream Effects of the Levee Overtopping at Wilkes-Barre, PA, During Tropical Storm Agnes |
| TP-11 | Survey of Programs for Water Surface Profiles | TP-38 | Water Quality Evaluation of Aquatic Systems |
| TP-12 | Hypothetical Flood Computation for a Stream System | TP-39 | A Method for Analyzing Effects of Dam Failures in Design Studies |
| TP-13 | Maximum Utilization of Scarce Data in Hydrologic Design | TP-40 | Storm Drainage and Urban Region Flood Control Planning |
| TP-14 | Techniques for Evaluating Long-Term Reservoir Yields | TP-41 | HEC-5C, A Simulation Model for System Formulation and Evaluation |
| TP-15 | Hydrostatistics - Principles of Application | TP-42 | Optimal Sizing of Urban Flood Control Systems |
| TP-16 | A Hydrologic Water Resource System Modeling Techniques | TP-43 | Hydrologic and Economic Simulation of Flood Control Aspects of Water Resources Systems |
| TP-17 | Hydrologic Engineering Techniques for Regional Water Resources Planning | TP-44 | Sizing Flood Control Reservoir Systems by Systems Analysis |
| TP-18 | Estimating Monthly Streamflows Within a Region | TP-45 | Techniques for Real-Time Operation of Flood Control Reservoirs in the Merrimack River Basin |
| TP-19 | Suspended Sediment Discharge in Streams | TP-46 | Spatial Data Analysis of Nonstructural Measures |
| TP-20 | Computer Determination of Flow Through Bridges | TP-47 | Comprehensive Flood Plain Studies Using Spatial Data Management Techniques |
| TP-21 | An Approach to Reservoir Temperature Analysis | TP-48 | Direct Runoff Hydrograph Parameters Versus Urbanization |
| TP-22 | A Finite Difference Method for Analyzing Liquid Flow in Variably Saturated Porous Media | TP-49 | Experience of HEC in Disseminating Information on Hydrological Models |
| TP-23 | Uses of Simulation in River Basin Planning | TP-50 | Effects of Dam Removal: An Approach to Sedimentation |
| TP-24 | Hydroelectric Power Analysis in Reservoir Systems | TP-51 | Design of Flood Control Improvements by Systems Analysis: A Case Study |
| TP-25 | Status of Water Resource Systems Analysis | TP-52 | Potential Use of Digital Computer Ground Water Models |
| TP-26 | System Relationships for Panama Canal Water Supply | TP-53 | Development of Generalized Free Surface Flow Models Using Finite Element Techniques |
| TP-27 | System Analysis of the Panama Canal Water Supply | TP-54 | Adjustment of Peak Discharge Rates for Urbanization |
| | | TP-55 | The Development and Servicing of Spatial Data Management Techniques in the Corps of Engineers |
| | | TP-56 | Experiences of the Hydrologic Engineering Center in Maintaining Widely Used Hydrologic and Water Resource Computer Models |
| | | TP-57 | Flood Damage Assessments Using Spatial Data Management Techniques |
| | | TP-58 | A Model for Evaluating Runoff-Quality in Metropolitan Master Planning |

- TP-59 Testing of Several Runoff Models on an Urban Watershed
- TP-60 Operational Simulation of a Reservoir System with Pumped Storage
- TP-61 Technical Factors in Small Hydropower Planning
- TP-62 Flood Hydrograph and Peak Flow Frequency Analysis
- TP-63 HEC Contribution to Reservoir System Operation
- TP-64 Determining Peak-Discharge Frequencies in an Urbanizing Watershed: A Case Study
- TP-65 Feasibility Analysis in Small Hydropower Planning
- TP-66 Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems
- TP-67 Hydrologic Land Use Classification Using LANDSAT
- TP-68 Interactive Nonstructural Flood-Control Planning
- TP-69 Critical Water Surface by Minimum Specific Energy Using the Parabolic Method
- TP-70 Corps of Engineers Experience with Automatic Calibration of a Precipitation-Runoff Model
- TP-71 Determination of Land Use from Satellite Imagery for Input to Hydrologic Models
- TP-72 Application of the Finite Element Method to Vertically Stratified Hydrodynamic Flow and Water Quality
- TP-73 Flood Mitigation Planning Using HEC-SAM
- TP-74 Hydrographs by Single Linear Reservoir Model
- TP-75 HEC Activities in Reservoir Analysis
- TP-76 Institutional Support of Water Resource Models
- TP-77 Investigation of Soil Conservation Service Urban Hydrology Techniques
- TP-78 Potential for Increasing the Output of Existing Hydroelectric Plants
- TP-79 Potential Energy and Capacity Gains from Flood Control Storage Reallocation at Existing U. S. Hydropower Reservoirs
- TP-80 Use of Non-Sequential Techniques in the Analysis of Power Potential at Storage Projects
- TP-81 Data Management Systems for Water Resources Planning
- TP-82 The New HEC-1 Flood Hydrograph Package
- TP-83 River and Reservoir Systems Water Quality Modeling Capability
- TP-84 Generalized Real-Time Flood Control System Model
- TP-85 Operation Policy Analysis: Sam Rayburn Reservoir
- TP-86 Training the Practitioner: The Hydrologic Engineering Center Program
- TP-87 Documentation Needs for Water Resources Models
- TP-88 Reservoir System Regulation for Water Quality Control
- TP-89 A Software System to Aid in Making Real-Time Water Control Decisions
- TP-90 Calibration, Verification and Application of a Two-Dimensional Flow Model
- TP-91 HEC Software Development and Support
- TP-92 Hydrologic Engineering Center Planning Models
- TP-93 Flood Routing Through a Flat, Complex Flood Plain Using a One-Dimensional Unsteady Flow Computer Program
- TP-94 Dredged-Material Disposal Management Model
- TP-95 Infiltration and Soil Moisture Redistribution in HEC-1
- TP-96 The Hydrologic Engineering Center Experience in Nonstructural Planning
- TP-97 Prediction of the Effects of a Flood Control Project on a Meandering Stream
- TP-98 Evolution in Computer Programs Causes Evolution in Training Needs: The Hydrologic Engineering Center Experience
- TP-99 Reservoir System Analysis for Water Quality
- TP-100 Probable Maximum Flood Estimation - Eastern United States
- TP-101 Use of Computer Program HEC-5 for Water Supply Analysis
- TP-102 Role of Calibration in the Application of HEC-6
- TP-103 Engineering and Economic Considerations in Formulating
- TP-104 Modeling Water Resources Systems for Water Quality
- TP-105 Use of a Two-Dimensional Flow Model to Quantify Aquatic Habitat
- TP-106 Flood-Runoff Forecasting with HEC-1F
- TP-107 Dredged-Material Disposal System Capacity Expansion
- TP-108 Role of Small Computers in Two-Dimensional Flow Modeling
- TP-109 One-Dimensional Model For Mud Flows
- TP-110 Subdivision Froude Number
- TP-111 HEC-5Q: System Water Quality Modeling
- TP-112 New Developments in HEC Programs for Flood Control
- TP-113 Modeling and Managing Water Resource Systems for Water Quality
- TP-114 Accuracy of Computed Water Surface Profiles - Executive Summary
- TP-115 Application of Spatial-Data Management Techniques in Corps Planning
- TP-116 The HEC's Activities in Watershed Modeling
- TP-117 HEC-1 and HEC-2 Applications on the MicroComputer
- TP-118 Real-Time Snow Simulation Model for the Monongahela River Basin
- TP-119 Multi-Purpose, Multi-Reservoir Simulation on a PC
- TP-120 Technology Transfer of Corps' Hydrologic Models
- TP-121 Development, Calibration and Application of Runoff Forecasting Models for the Allegheny River Basin
- TP-122 The Estimation of Rainfall for Flood Forecasting Using Radar a Rain Gage Data